UPDATE: NASA’s Moon-to-Mars Planetary Autonomous Construction Technology (MMPACT) Demonstration and Qualification Missions Concepts

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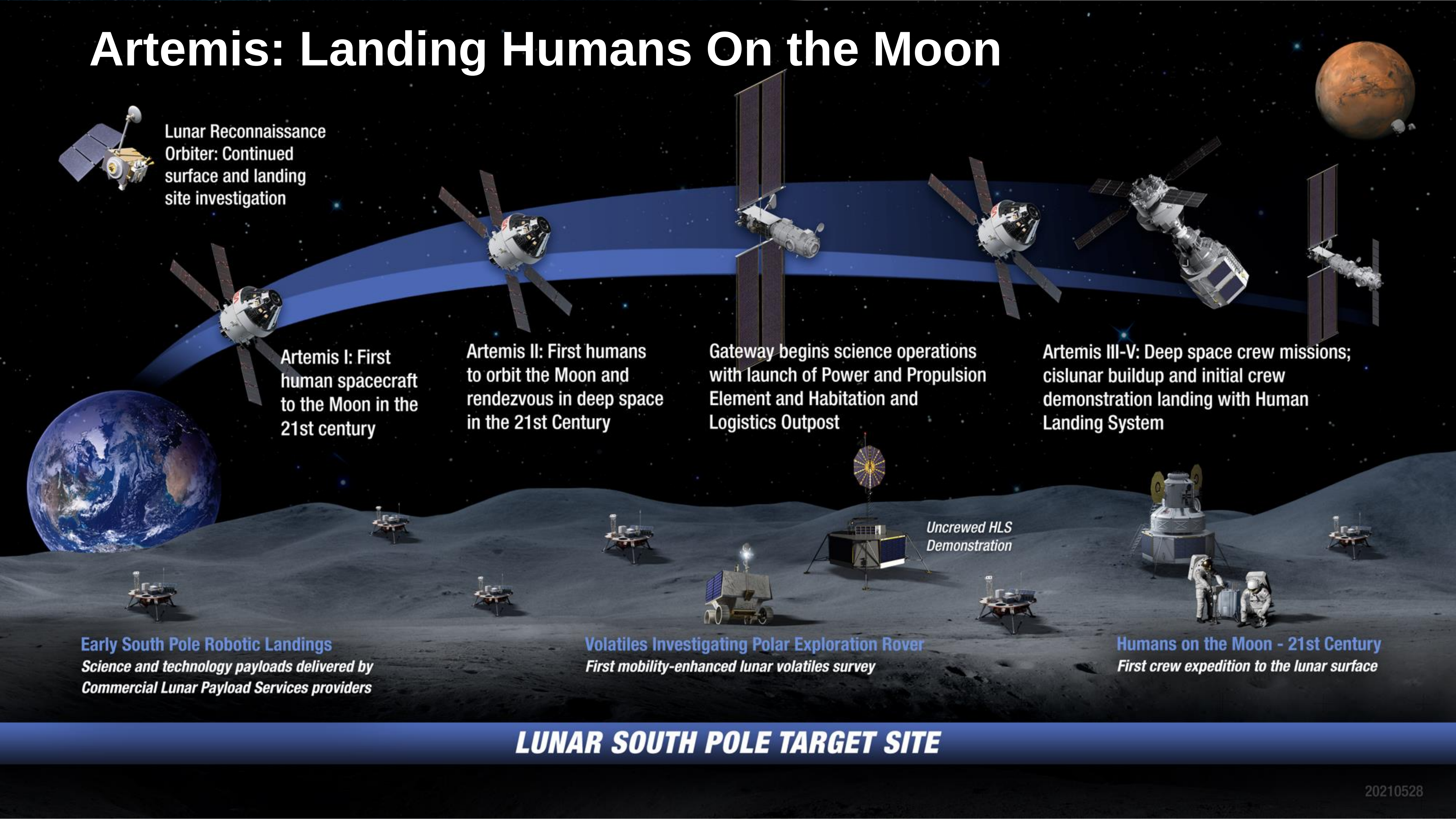
Moon Village Association Architecture Concepts Working Group Workshop

January 25, 2022

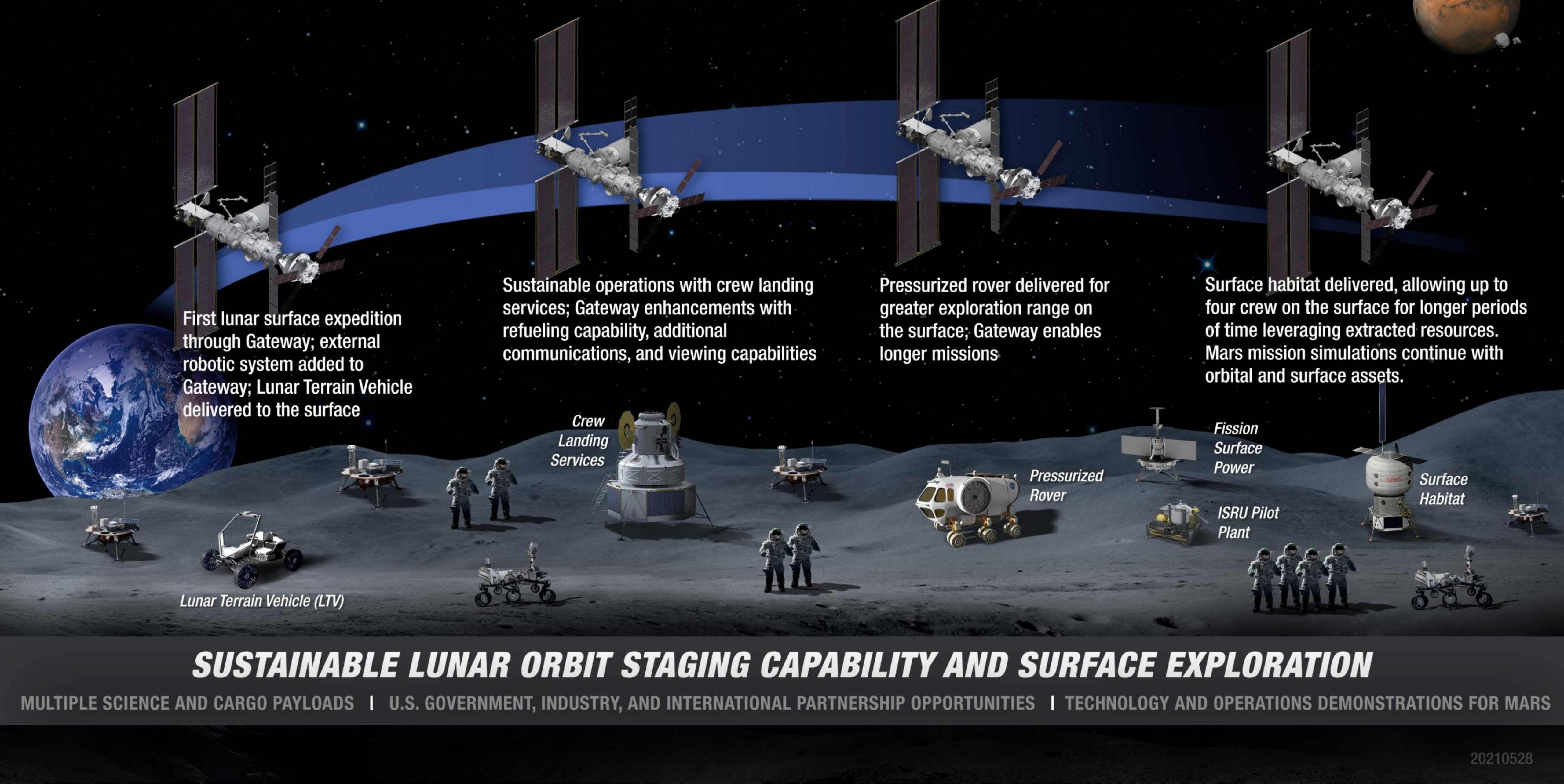
Agenda

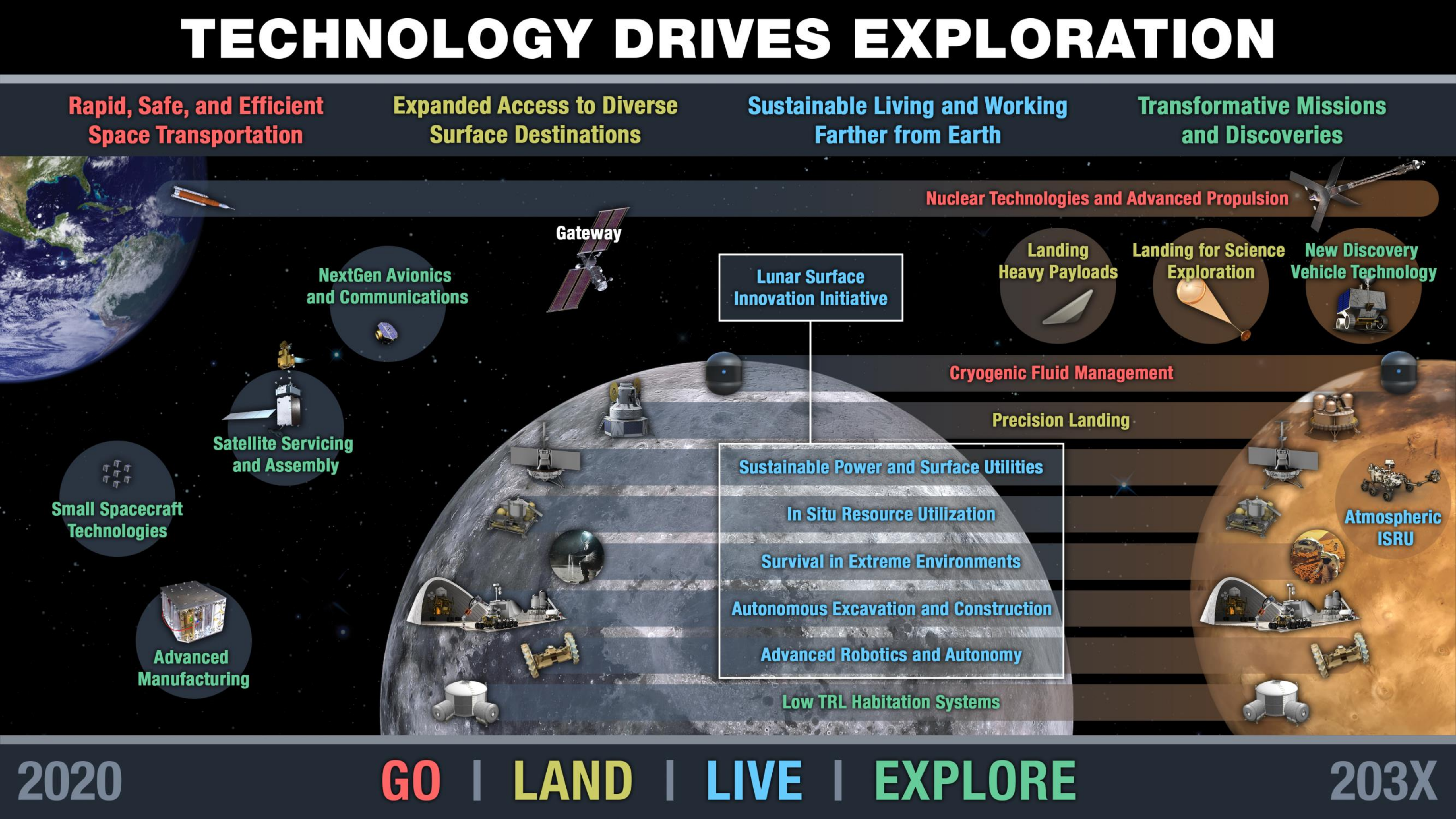
- Artemis: Phases 1 and 2
- Space Technology Mission Directorate: Technology Drives Exploration
    - Lunar Surface Innovation Initiative (LSII)
        - Excavation, Construction, and Outfitting (ECO)
        - MMPACT Overview
        - Construction Technology Demonstration and Qualification Mission Concepts
        - Challenges and Capability Gaps
- Questions

Artemis: Landing Humans On the Moon



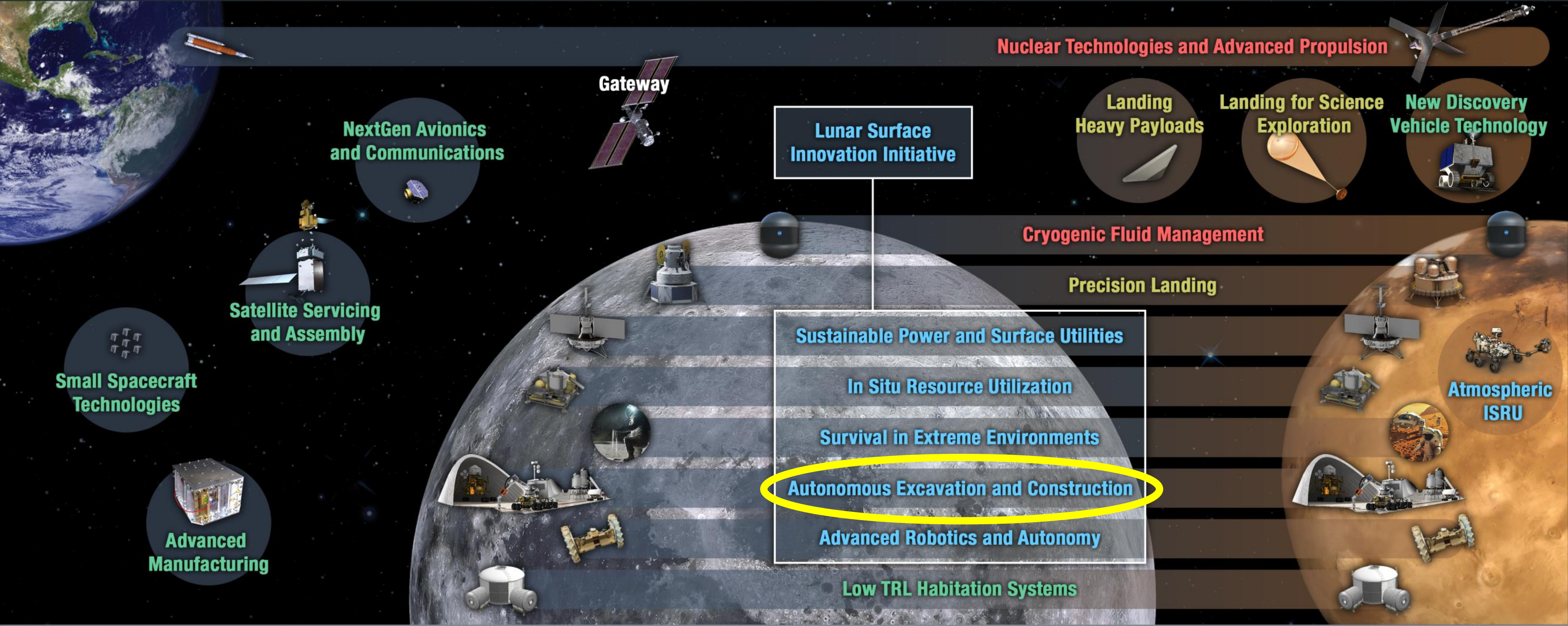
Artemis Base Camp Buildup




TECHNOLOGY DRIVES EXPLORATION
Rapid, Safe, and Efficient Space Transportation
Expanded Access to Diverse Surface Destinations
Sustainable Living and Working Farther from Earth
Transformative Missions and Discoveries
Nuclear Technologies and Advanced Propulsion
Gateway
NextGen Avionics and Communications
Lunar Surface Innovation Initiative
Landing Heavy Payloads
Landing for Science Exploration
New Discovery Vehicle Technology
Satellite Servicing and Assembly
Small Spacecraft Technologies
Advanced Manufacturing
Cryogenic Fluid Management
Precision Landing
Sustainable Power and Surface Utilities
In Situ Resource Utilization
Survival in Extreme Environments
Autonomous Excavation and Construction
Advanced Robotics and Autonomy
Low TRL Habitation Systems
Atmospheric ISRU
2020
GO | LAND | LIVE | EXPLORE
203X

TECHNOLOGY DRIVES EXPLORATION

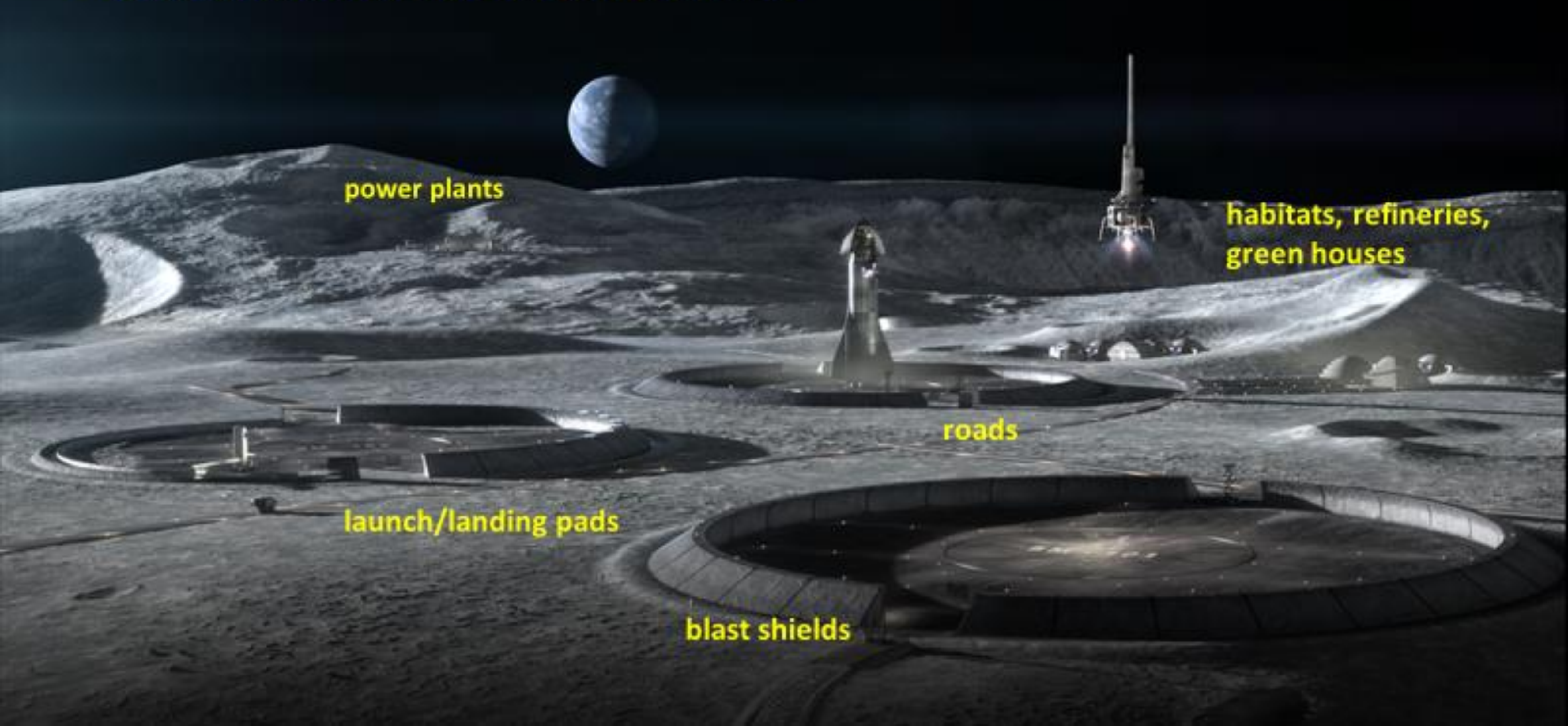
Rapid, Safe, and Efficient Space Transportation | Expanded Access to Diverse Surface Destinations | Sustainable Living and Working Farther from Earth | Transformative Missions and Discoveries



2020 GO | LAND | LIVE | EXPLORE 203X

Building a Sustainable Presence on the Moon

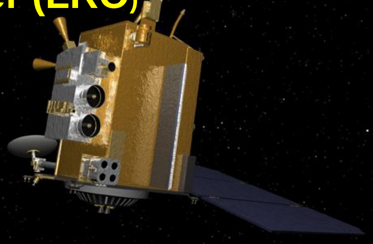
- What infrastructure are we going to need?

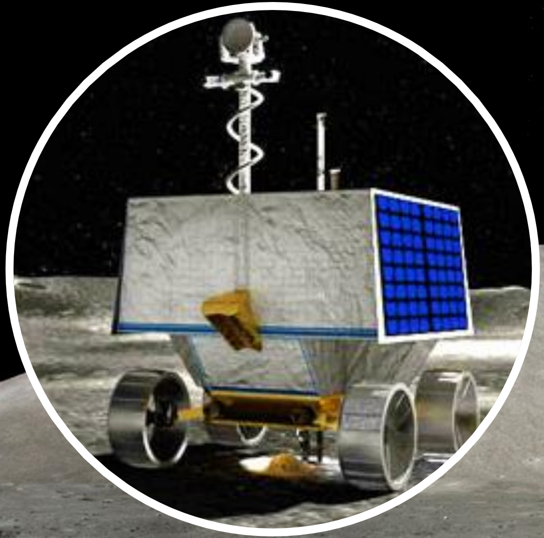


Excavation for ISRU and Construction:
Finding, Excavating and Transporting the Resources

Resource Prospecting –
Looking for Resources

Lunar Reconnaissance Orbiter (LRO)



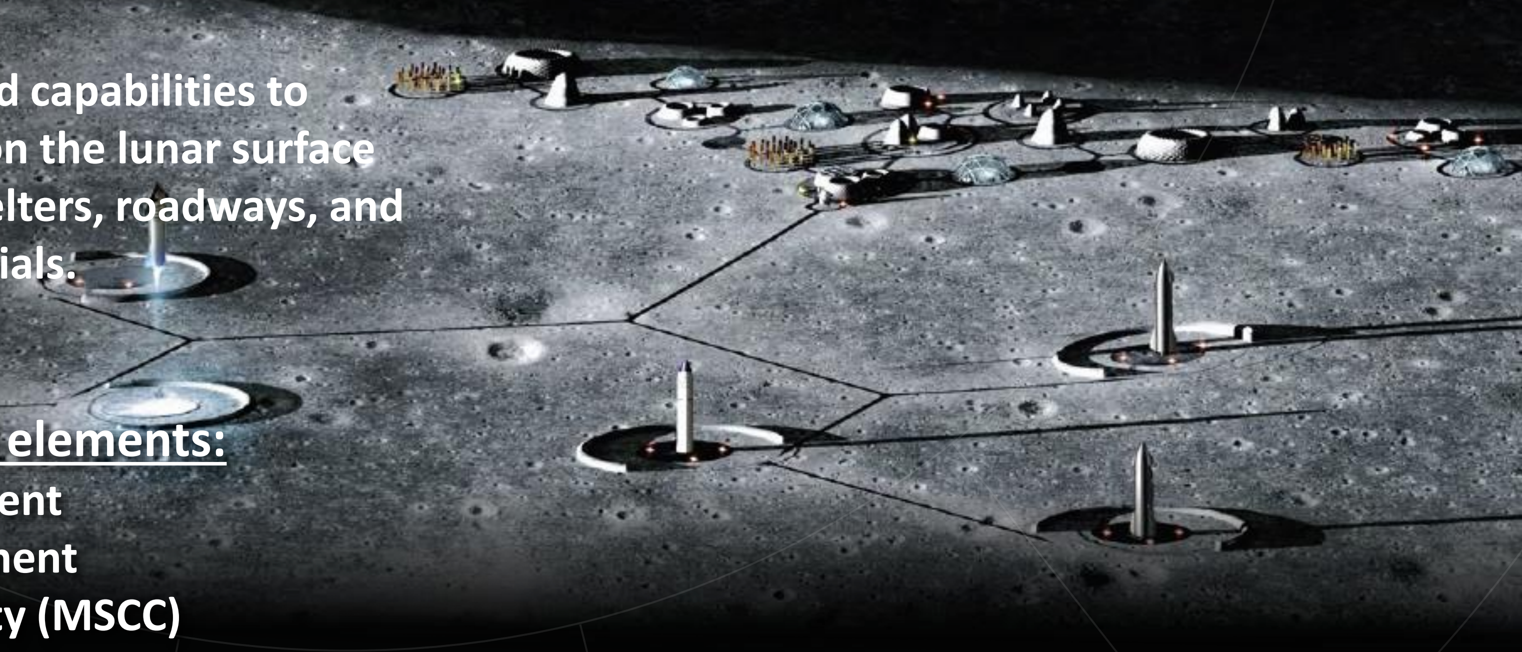


Volatiles Investigating Polar Exploration Rover (VIPER)
~2024 mission

Excavation & Processing for Aggregates and Binders

RASSOR Excavator
~2026 mission

Moon-to Mars Planetary Autonomous Construction Technologies (MMPACT) Overview



GOAL

Develop, deliver, and demonstrate on-demand capabilities to protect astronauts and create infrastructure on the lunar surface via construction of landing pads, habitats, shelters, roadways, and blast shields using lunar regolith-based materials.

MMPACT is structured into three interrelated elements:

1. Olympus Construction Hardware Development
2. Construction Feedstock Materials Development
3. Microwave Structure Construction Capability (MSCC)

OBJECTIVES

- Develop and demonstrate additive construction capabilities for various structures as materials evolve from Earth-based to exclusively *In Situ* Resource Utilization (ISRU)-based.
- Develop and demonstrate approaches for integrated sensors and process monitoring in support of *in situ* verification & validation of construction system and printed structures.
- Test and evaluate Olympus and MSCC products for use in the lunar environment.
- Validate that Earth-based development and testing are sufficient analogs for lunar operations

MMPACT ELEMENTS, STRUCTURE, AND TEAM MEMBERS

PI: Clinton | **CE: Burlingame**
PM: Edmunson | **LSE: Thompson**

Resource Analyst: Clark

Construction Feedstock Materials Development
Edmunson

- MSFC CANs
  - Mississippi State University (2)
  - Branch Technologies
- MSFC CIFs (pending)
  - Mississippi State University
  - South Dakota School of Mines and Technology
- Penn State University (PSU) - NSTGRO

Olympus – Autonomous Construction System
Fiske

- AFWERX SBIR (W/AFCEC/TANG/DIU)
  - ICON Technologies
    - SEArch+
    - Bjarke Ingels Group
    - Blue Origin
    - Colorado School of Mines
- Jacobs
- LaRC
- MSFC CANs
  - UAH
  - University Of Mississippi
  - Drake State (2)
  - Sinte Gleska University
  - Blue Origin (In Review)
  - UAH (In Review)
  - Clarkson/PSU (In Review)
  - University Of Mississippi (In Review)
  - Kappler (In Review)
  - CANVAS (In Review)

Microwave Structure Construction Capability
Effinger

- JPL
- KSC
  - SURA
- LaRC
- Jacobs
- Dr. Holly Shulman
  - Microwave Properties North
- Radiance Technologies
- RW Bruce Assoc. LLC
  - JP Gerling Microwave Applications
  - Crown College
  - Space Resources Extraction Technologies
  - Microwave Materials Technologies
- Southern Research
- Aerie Aerospace
- MTS
- Logical Innovations
- Universities (2 Pending - FY22 Starts)

Autonomous Construction for the Lunar Outpost

Regolith-based Materials and Processes:

- Cementitious
- Geopolymers/Polymers
- Thermosetting materials
- Regolith Melting/Forming
- Laser sintered
- Microwave sintered

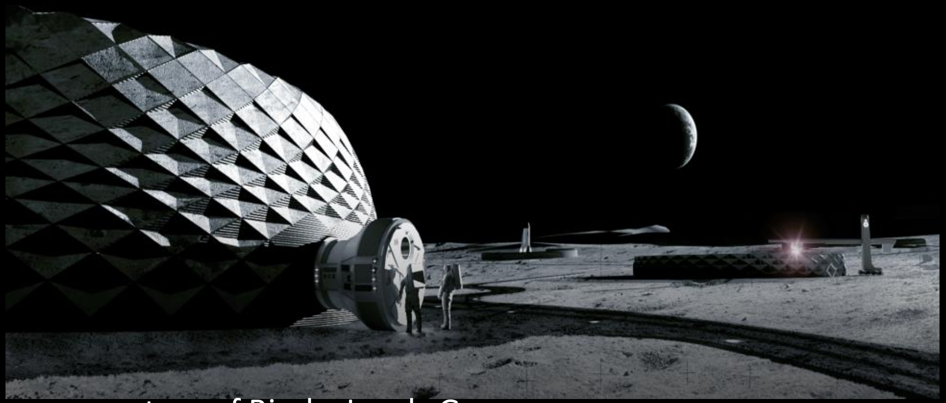


Image courtesy of Bjarke Ingels Group

Image courtesy of ICON

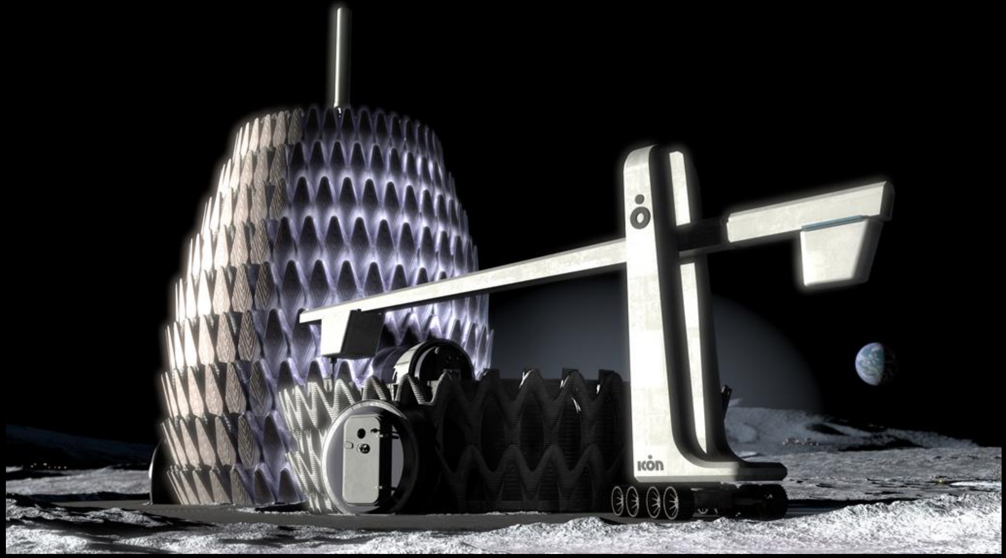
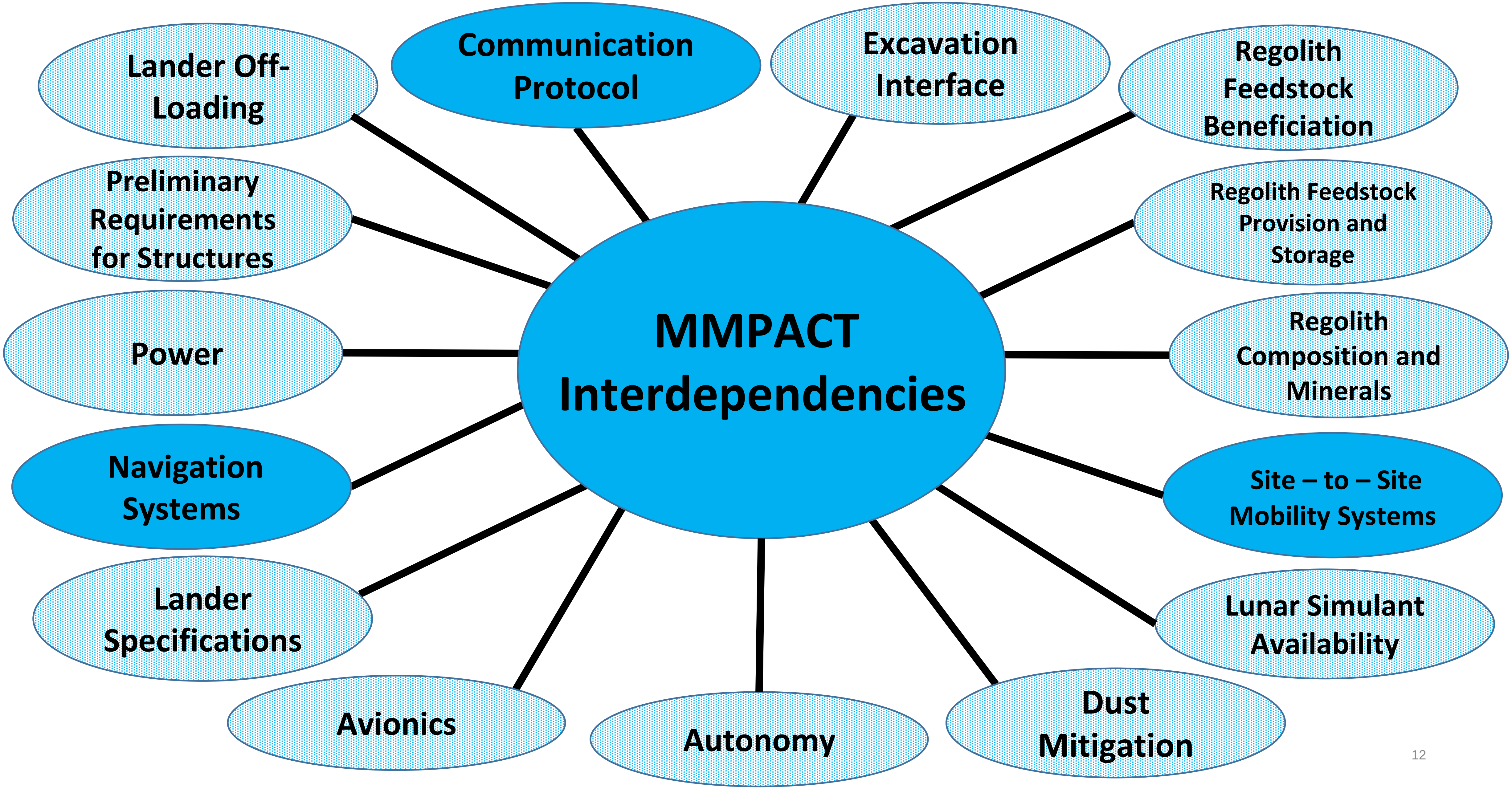


Image courtesy of SEArch+

MMPACT Interdependencies (Primarily DM-2 and Beyond)



Excavation and Construction Roles and Responsibilities

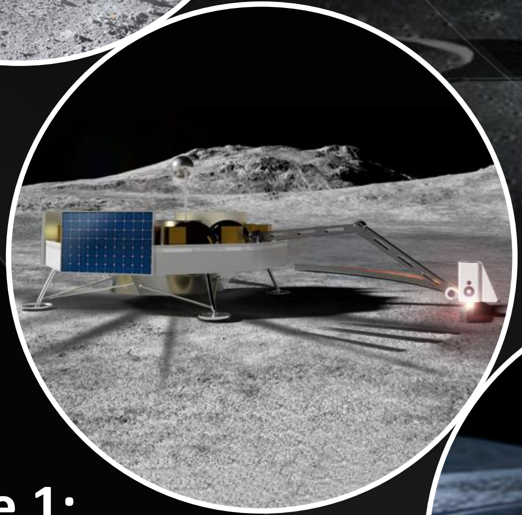
- Excavation Roadmap
  - Dirt Work
    - Site Prep
    - Leveling/Grading
    - Compacting
    - Cut/Fill
    - Berms
    - Regolith Delivery
    - Size Sorting (TBD)
    - Burial
    - Trenching
    - Overburden
    - Regolith radiation shielding
    - Roads (gravel, compacted)

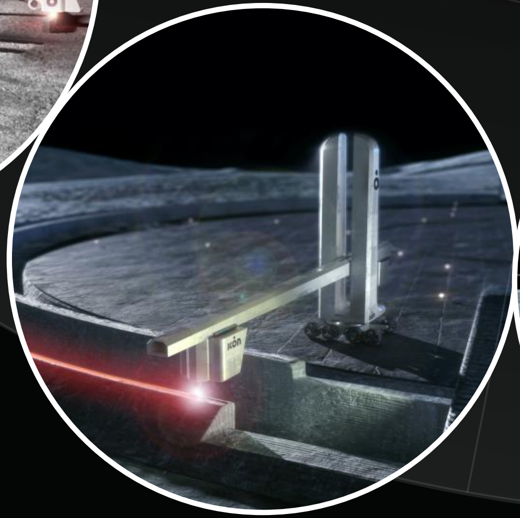
Technology Trades Inform Roadmaps

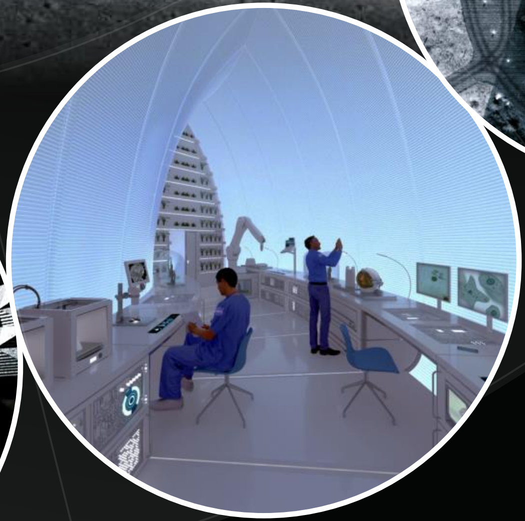
- Artemis Architecture
- New Data
- MMPACT
- LSH
- REACT ACO
- In-Situ Construction
- Pilot Excavator
- BEAST
- SBIR/STTRs
- Graduate Fellowships
- Big Ideas
- ESI Academia

- Construction Roadmap
  - Horizontal & Vertical Construction
    - Sintering
      - Microwave
      - Solar
      - Laser
      - Thermal
    - Regolith Binding
      - Cementitious
      - Polymers
      - Sodium Silicate
    - Regolith Bagging
    - Stabilization (other than compaction)
    - Unpressurized structures
    - Pressurized structures
    - Landing Pads
    - Blast Shields
    - Roofs
      - Radiation Shielding
    - Lifting and Robotic Assembly
    - Foundations
    - Footers
    - Walls
    - Roads
    - Dust Free Zones

Lunar Construction Capability Development Roadmap







Phase 1: Develop & demonstrate excavation & construction capabilities for on-demand fabrication of critical lunar infrastructure such as landing pads, structures, habitats, roadways, blast walls, etc.

Phase 2: Establish lunar infrastructure construction capability with the initial base habitat design structures.

Phase 3: Build the lunar base according to master plan to support the planned population size of the first permanent settlement (lunar outpost).

Phase 4: Complete build-out of the lunar base per the master plan and add additional structures as strategic expansion needs change over time.

Current STMD Planning Manifest for EC&O DM and QM

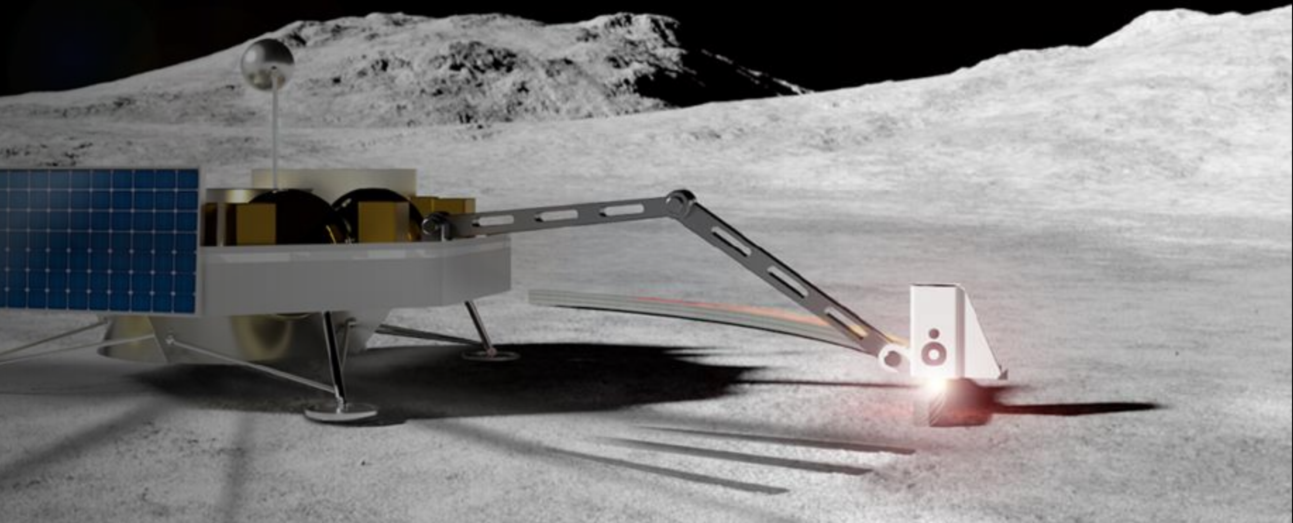
PRELIMINARY PLANNING SUBJECT TO REVIEW

- Demonstration Mission 1 (DM-1) – 2026
- Demonstration Mission 2 (DM-2) - 2028
- Qualification Mission 1 (QM-1) – 2030
- Qualification Mission 2 (QM-2) - 2032

Initial Construction Technology Demonstration Mission, DM-1 (2026)

Construction Roadmap

- Demonstrate downselected construction technique utilizing ISRU materials at small scale from lander base (horizontal and vertical subscale “proof of concept” elements)
- Results are critical to inform future construction demonstrations & characterize ISRU-based materials and construction processes for future autonomous construction of functional infrastructure elements
- Demonstration of remote/autonomous operations
- Initial demonstration of instrumentation and material
- Validation that Earth-based development and testing are sufficient analogs for lunar operations
- Anchors analytical models
- ***Rationale:*** *Must prove out initial construction concept in lunar environment*



Outcome

- **TRL 6** achieved for autonomous ISRU consolidation into densified, subscale horizontal and vertical demonstration products
- **TRL 9** for limited hardware and instrumentation that will be used on later missions

PRELIMINARY PLANNING SUBJECT TO REVIEW

Construction Technology Demonstration Mission, DM-2 (Target: 2028)
Subscale Landing Pad Construction Demonstration

Construction Roadmap

- Subscale ISRU-based LLP construction demonstration and vertical blast shield construction demonstration
  - ~25' diameter pad at least 6" thick
  - ~10' long, 3' tall blast shield on the perimeter
  - Scale/dimensions TBR with PT and Excavation Team
- Mobile Autonomous Construction System
- Demonstrate interface with Excavation System (site prep, regolith feedstock provision) - Critical
- Increased instrumentation for in-process monitoring and NDE capabilities on printed pad materials characterization
- Requires key interdependencies to be functional (e.g. Power, Comm and Nav, etc)
- ***Rationale:*** Prove autonomous ISRU construction technology and mobility at reduced scale for horizontal and vertical structural elements prior to full scale

Investigate in situ test methods for determining thermal performance and mechanical loading (landing loads) on subscale LLP

- ***Rationale:*** Need to verify construction roadmap pad performance under launch/landing conditions prior to building full scale pad

Outcome

- **TRL 7** pad surface and vertical structure (blast shield) (if a hopper lands on the consolidated pad, then TRL 9 for CLPS-scale (hopper) landers)
- **TRL 9** for specific construction hardware and instrumentation

PRELIMINARY PLANNING SUBJECT TO REVIEW

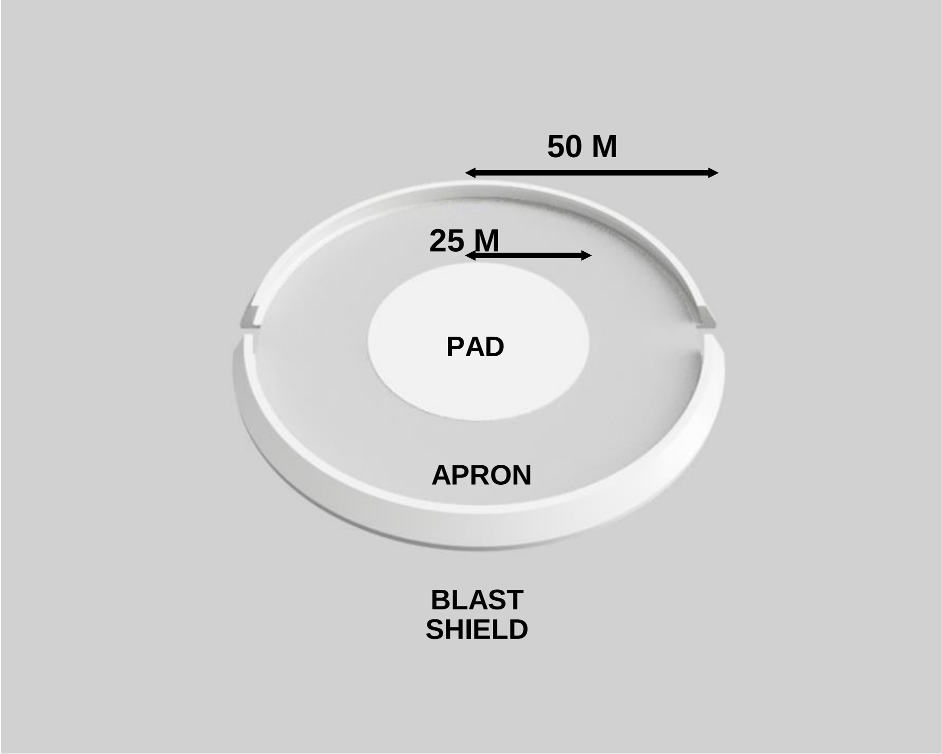
Construction Technology Qualification Mission, QM-1 (Target: 2030)
Operational Pad Construction

Construction Roadmap

Demonstrate autonomous construction of:

- 25 m radius autonomously constructed, consolidated lunar landing pad
- Additional 25 m radius (50 m total radius) autonomously constructed, consolidated apron with entry/exit ramp (resolve scale/dimensions TBD)
- Full-perimeter surface-hardened blast shield – for example, 2.6 m tall at 3 degree angle off horizontal for a 50M radius LLP - with opening for ingress-egress. (Pending updated PSI analyses of ejecta profile)
- Scale/dimensions TBR with PT and Excavation Team
- Subscale unpressurized shelter (10' tall, 15' wide)

- ***Rationale:***
  - Must prove berm building and pad site prep at full scale
  - Must prove interface between construction and excavation system at full scale



PRELIMINARY PLANNING SUBJECT TO REVIEW

Outcome

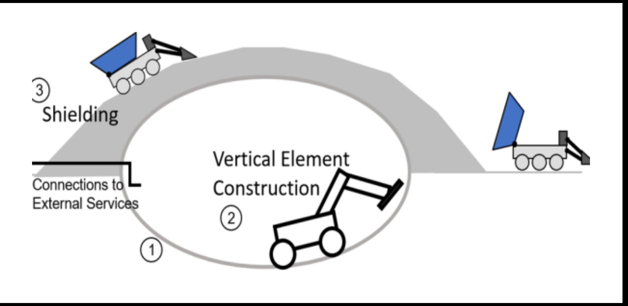
- In 2030 we have an operational landing pad at Artemis base location suitable for landing of subsequent CLPS and HLS landers supporting sustained operations (pending resolution of scale/dimensions TBD)
- Construction Roadmap: TRL 9 construction system for full scale horizontal infrastructure elements
- Construction system ready for commercialization

PRELIMINARY PLANNING
SUBJECT TO REVIEW

QM-2
Lunar Safe Haven

Construction Roadmap
- Target safe haven type structural elements for previous vertical construction demos (DM-1, DM-2, QM-1)
- Full scale unpressurized shelter (20’ tall, 30’ wide) (scale/dimensions TBR with PT and LSH Team)
- Demo LSH structure in QM-2

Outcome
- **TRL 9** achieved for autonomous ISRU consolidation into densified, full scale vertical infrastructure elements
- **TRL 9** for specific construction hardware and instrumentation



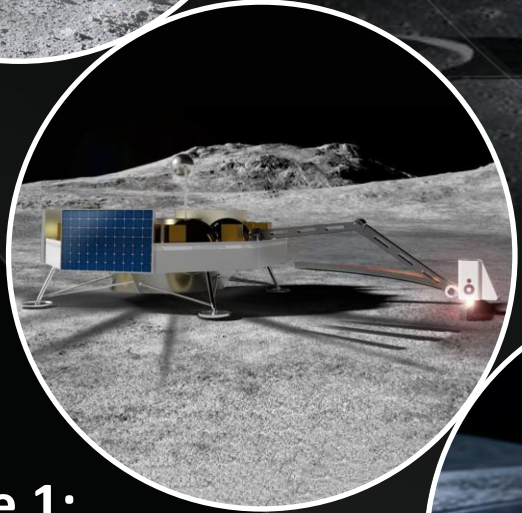
USMC Printed Vehicle Hide
3D-printed and assembled vehicle hide constructed by ICON for the USMC.

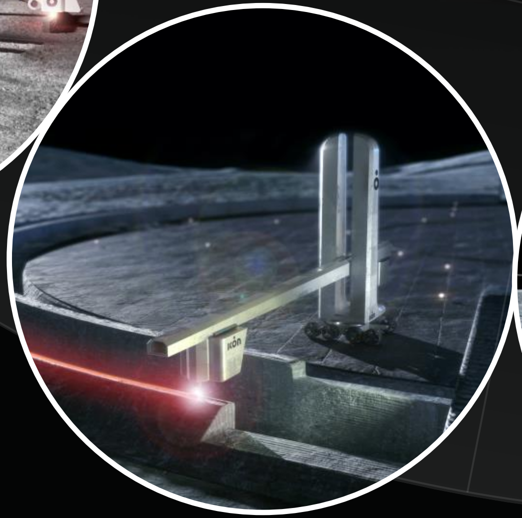
Mars Dune Alpha (CHAPEA)
3D-printed Martian habitat analog under construction at JSC by MMPACT members ICON + BIG.

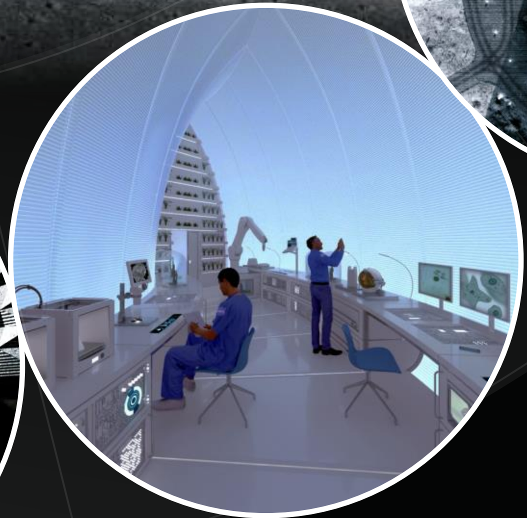
Excavation Roadmap
Vertical construction via the Excavation roadmap.

Lunar Construction Capability Development Roadmap

Phase 4: Complete build-out of the lunar base per the master plan and add additional structures as strategic expansion needs change over time.







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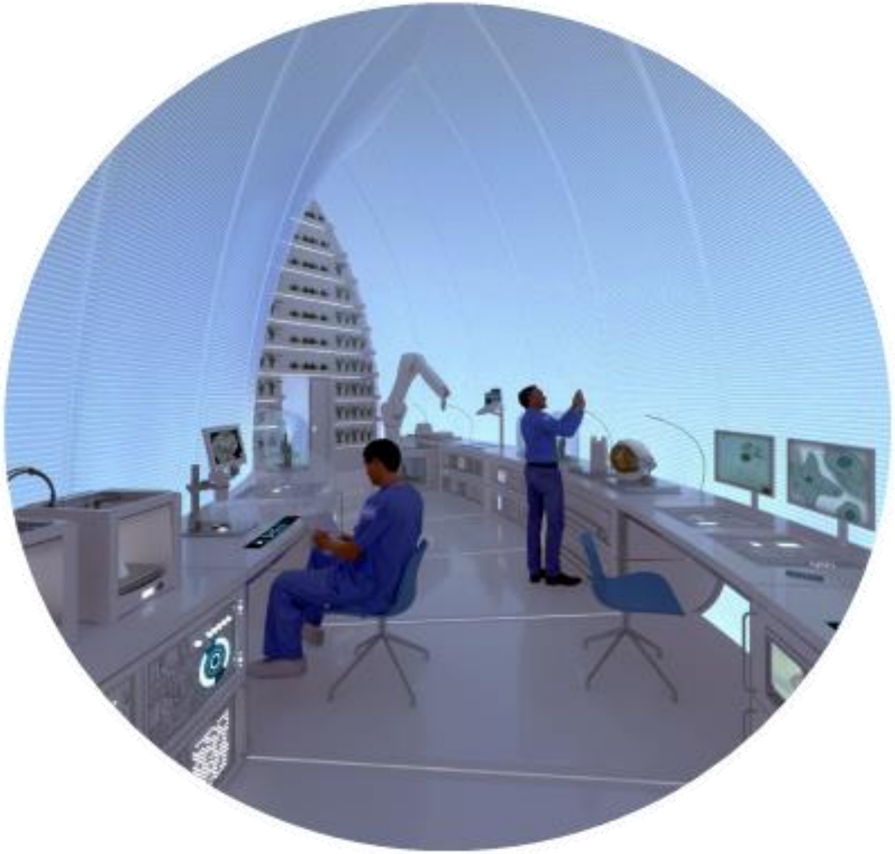
Phase 3: Build the lunar base according to master plan to support the planned population size of the first permanent settlement (lunar outpost).

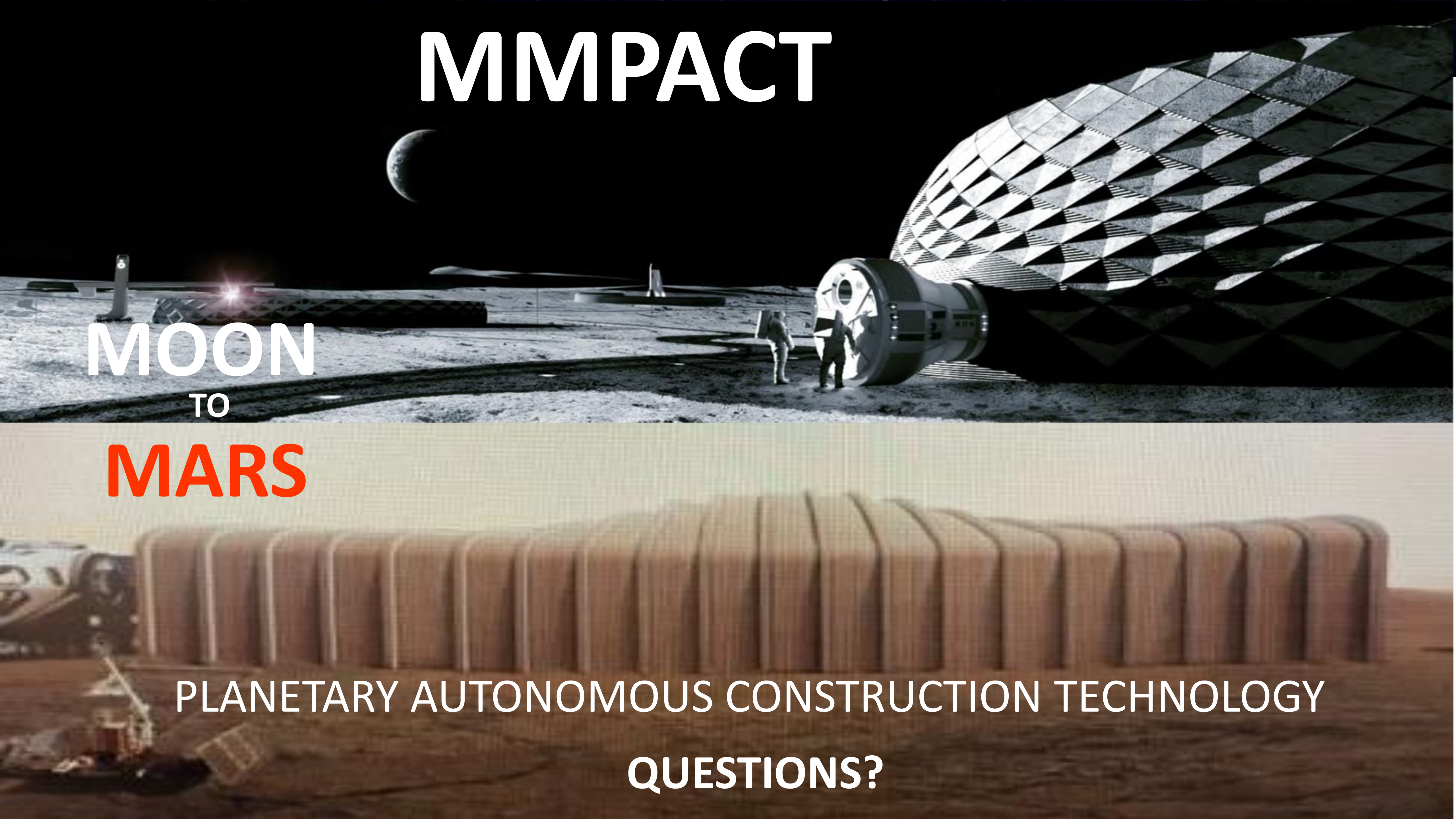
Lunar Outfitting Capability Development

- Outfitting: Broad spectrum of capabilities – "Turning a house into a home"
- In-situ installation of subsystems
  - Mechanical
  - Electrical
  - Plumbing (ducting, piping, gas storage)
- Interior Furnishings Fabrication
  - Workbenches
  - Tables
  - Chairs
- Power, Lighting, Communications
- Enclosures (windows, hatches, bulkheads)
- Verification, Validation, and Inspection Technologies



Challenges and Capability Gaps

- Reduced gravity and low reaction forces – Excavation
- Inspection and Certification of as-built structure – Construction
- Material and construction requirements and standards - Construction
- Process Development and Demonstration
  - ISRU for extraction of basic products:
    - Consumables – water, oxygen, and volatiles capture
    - Feedstock materials – metals, alloys and binder constituents
  - Construction: Deposition processes and associated materials
- Scale Up
  - ISRU production (10's to 100's mT)
  - Excavation: (10's to 1000s mT); Trips/Distance traversed
  - Construction: Proof of concept to full scale landing pads and habitats
- Regolith excavation, transfer, and conveyance
- Long-duration operation of mechanisms and parts under lunar environmental conditions (Reliability and Maintainability)
- Structural Health Monitoring and Repair
- Dust Mitigation
- Increased Autonomy of Operations
- Power


MMPACT
MOON
TO
MARS
PLANETARY AUTONOMOUS CONSTRUCTION TECHNOLOGY
QUESTIONS?

In-Space Manufacturing Project Portfolio

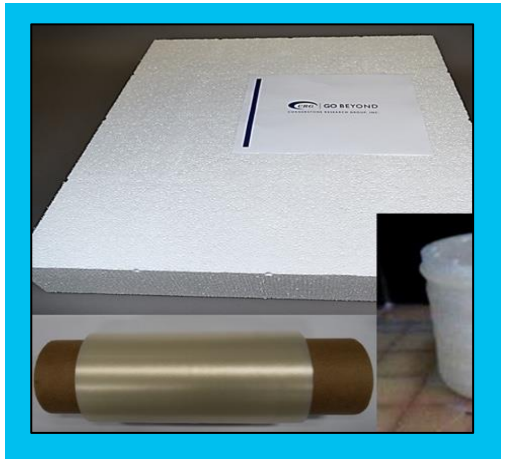
Objective: provide a solution towards sustainable, flexible missions through development of on-demand fabrication, replacement, and recycling capabilities

On Demand Metals Manufacturing

Provide a capability for on-demand 3D printing of metal parts

Image Courtesy of Made In Space

Recycling and Reuse



Develop materials and recycling technologies to create an on-orbit recycling ecosystem

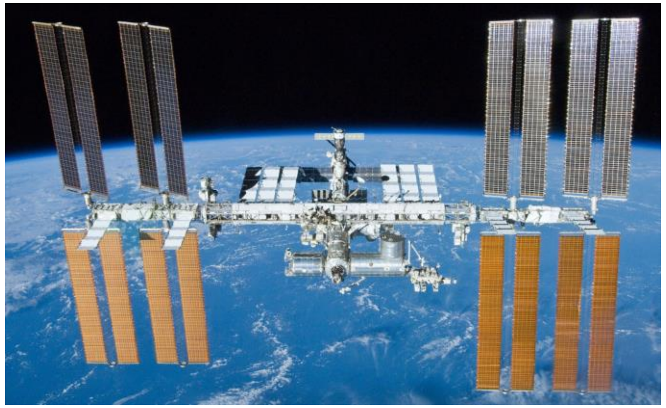
Image Courtesy of Cornerstone Research Group

On Demand Electronics Manufacturing

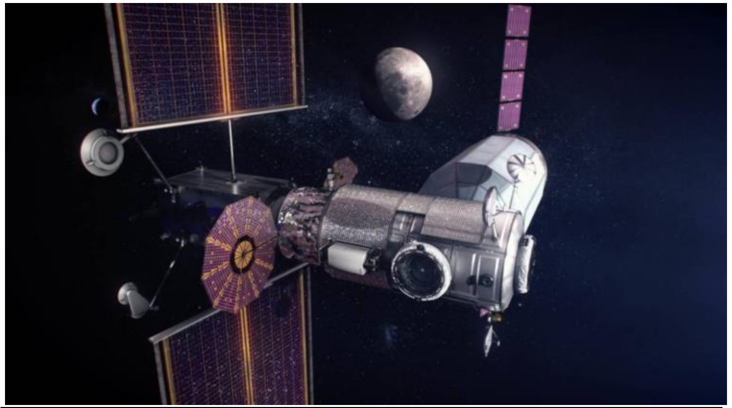
Develop printed electronics, sensors, and power devices for testing and demonstration on ISS

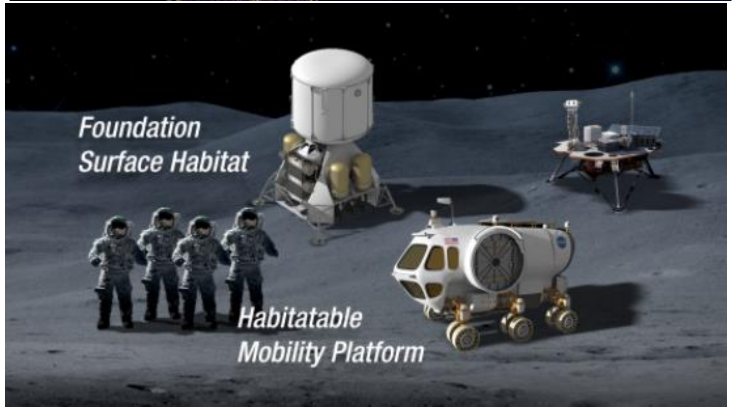
The Vision of Space Sustainability

Manufacturing in space is a destination-agnostic capability and has clear mission benefits beyond low earth orbit, where cargo resupply opportunities become more limited. These technologies are key enablers for sustainable space exploration.



ISS is the testbed for ISM.

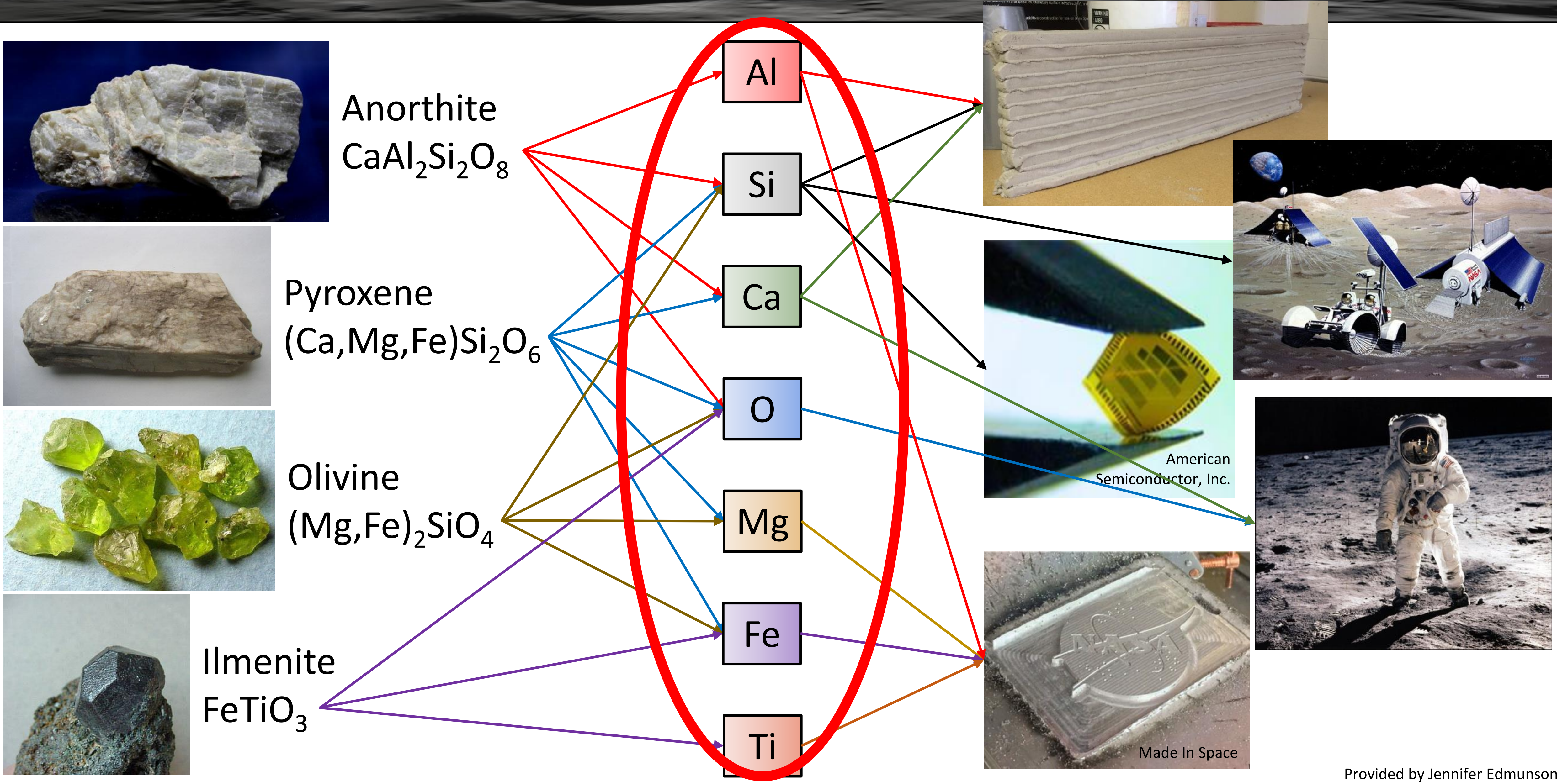




ISM capabilities demonstrated on ISS are applicable to Gateway and the lunar surface.

"Houston, we have a solution."

Lunar regolith must be used for multiple applications (consumables, manufacturing, infrastructure construction) to enable a sustainable human presence and future lunar economy



Provided by Jennifer Edmunson